Proceedings of the 2nd International Conference on Financial Technology and Business Analysis
DOI: 10.54254/2754-1169/62/20231344

Using Linear Regressions Analyzing the Impact of Medical Technology Inputs on Economic Output in China and Brazil

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Abstract: In the current era of globalization, the relationship between healthcare investments and economic outcomes has emerged as a pivotal research focus. Researchers have made significant strides in understanding this relationship; however, certain knowledge gaps and disparities in explanations persist. This underscores the importance of investigating the impact of healthcare investments on economic outcomes, particularly in the contexts of two distinct yet influential developing countries, China and Brazil. This study delves into the intricate interplay between healthcare investments and economic outcomes in China and Brazil. Using a comprehensive dataset from the World Health Organization (WHO), including capital health expenditures, domestic government health expenditures, and more. Then we employ the linear regression analysis in tandem with these indicators to investigate the relationship between them and economic output. This research also considers non-data-based variables, such as policies and national economic conditions, to ensure the accuracy of our findings. Our findings reveal that healthcare expenditures, particularly Government General Healthcare Expenditure (GGHE-D) and External Health Expenditure (EXT), significantly impact China's GDP growth. In contrast, Brazil exhibits a distinct pattern, with GGHE-D negatively impacting its economic output while Transfers from Government Domestic Revenue (TransGDR) that allocated to health contribute positively. These distinctions highlight the diverse effects of healthcare spending on the economies of the two nations. In conclusion, this research underscores the need for tailored healthcare policies in the context of economic structures and the significance of evidence-based decision-making. It also highlights the potential of international cooperation in healthcare to drive GDP growth and healthcare innovation.

Keywords: Healthcare, Linear Regression Analysis, China, Brazil

1. Introduction

In today's context of globalization, national health-care systems and economies are closely interrelated. Investments in healthcare not only influence the well-being of the populace but also wield a significant influence on the economic productivity of the nation. China and Brazil, as developing countries and BRICS countries, have many similarities, but also have different national conditions and healthcare systems, which makes the economic impact of their healthcare investments an important issue. To be more specific, China has 34 provinces covering 9.6 million square kilometers and an economy that is nine times larger than Brazil's at $17.73 trillion. Brazil has 26

DOI: 10.54254/2754-1169/62/20231344

states covering 8.15 million square kilometers, but its universal healthcare system, Sistema Único de Saúde (SUS), stands as the largest public health system globally, ensuring that 75 percent of its 210 million people have access to healthcare [1].

In responding to the COVID-19 pandemic, China and Brazil chose different strategic paths. China adopted a containment strategy to curb the spread of the virus through strict embargoes and prevention and control measures, while Brazil adopted a mitigation strategy, focusing more on lessening the economic and social impact of the outbreak. Differences in the two countries' investment in the healthcare sector led to the choice of these two different strategies, with China's large investment in healthcare resources in the previous years supporting containment measures, while Brazil placed more emphasis on economic recovery [2]. This raises an important question: did this different healthcare investment strategy have different impacts on the economic output of China and Brazil?

The importance of this question cannot be overstated. Firstly, understanding the relationship between inputs and economic output in healthcare helps governments and policymakers better plan healthcare resources and formulate economic policies. Secondly, for large countries such as China and Brazil, an in-depth study of their domestic situation is exemplary for both the global healthcare and economic sectors. Finally, by comparing the situations in China and Brazil, we can extract generalized lessons that can provide useful references for other countries.

This study focuses on investigating how inputs in the healthcare sector affect the economic output of both China and Brazil. Based on the data provided by World Health Organization (WHO) in the Table 1 and variables in the Table 2 on China's and Brazil's inputs in the medical field, including capital health expenditures, domestic general government health expenditures, etc., linear regression analysis can be used to determine the correlation between these inputs and economic output. Other non-data-based variables, such as policies and national economic conditions, will also be considered to ensure the accuracy of the study's results. Ultimately, the goal of this study is to provide important insights to governments and policymakers in China and Brazil about how inputs in the healthcare field affect economic output. Through this study, we hope to provide practical recommendations for improving healthcare system management and economic policymaking for sustainable development in these two countries, as well as provide a reference for providing solutions to similar problems in other countries.

Table 1: Variables included in the study.

Types of Variables	Variables Name
Dependent Variable	Gross Domestic Product (GDP)
Independent Variable	Capital Health Expenditure (CHE)
	Domestic General Government Health Expenditure (GGHE-D)
	External Health Expenditure (EXT)
	Transfers from government domestic revenue (TransGDR)

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Table 2: Economic indicators in China and Brazil from World Health Organization.

	GDP (in million current US$)		CHE (in million current US$)		GGHE-D (in million current US$)		EXT (in million current US$)		TransfGDR (allocated to health purposes)(in million current US$)	
	China	Brazil	China	Brazil	China	Brazil	China	Brazil	China	Brazil
2,000	1,205,519	655,449	856	4,197	11,943	22,745	14	174	10,439	22,745
2,001	1,333,665	559,984	2,206	3,925	13,000	19,672	126	136	10,051	19,672
2,002	1,465,837	509,796	2,797	3,657	16,309	18,793	93	140	11,530	18,793
2,003	1,656,954	558,234	3,422	2,972	20,769	19,591	93	90	13,352	19,591
2,004	1,949,492	669,289	5,116	4,261	25,315	23,204	103	289	15,320	23,204
2,005	2,290,094	891,634	6,750	6,287	31,328	29,827	201	48	18,644	29,827
2,006	2,754,113	1,107,627	8,201	8,220	38,203	39,224	158	97	22,406	39,224
2,007	3,555,679	1,397,114	9,634	10,928	50,995	48,684	236	94	30,604	48,684
2,008	4,577,397	1,695,855	13,473	14,266	79,481	59,430	278	73	46,605	59,430
2,009	5,088,993	1,666,996	21,236	13,753	109,343	61,803	234	209	64,656	61,803
2,010	6,033,813	2,208,838	25,010	6,819	132,502	79,010	311	432	78,024	79,010
2,011	7,492,257	2,616,157	29,567	6,887	174,795	90,668	246	691	104,208	90,668
2,012	8,539,473	2,465,229	34,897	7,535	217,311	82,699	219	238	126,453	82,699
2,013	9,625,044	2,472,819	42,540	6,984	258,901	87,813	252	134	147,176	87,813
2,014	10,524,211	2,456,043	52,000	9,161	293,735	90,846	152	285	158,604	90,846
2,015	11,113,528	1,802,212	63,389	5,218	330,284	69,455	47	129	188,097	68,246
2,016	11,227,075	1,795,693	69,361	5,696	324,821	70,902	9	122	172,821	69,917
2,017	12,265,317	2,063,515	77,685	5,231	352,141	81,574	3	129	180,367	80,382
2,018	13,841,901	1,916,934	87,433	6,448	403,567	74,554	5	155	203,978	73,153
2,019	14,340,666	1,873,288	83,381	5,479	429,508	73,377	5	263	213,003	72,383
2,020	14,862,527	1,448,566	92,430	3,073	454,947	66,854	2	217	244,763	66,071

2. Description of China

The data from the WHO in Table 1, spanning from the year 2000 to 2020, reveals significant economic growth in China, with the GDP steadily increasing from 1,205,519 million current US$ in 2000 to 14,862,527 million current US$ in 2020. Over this period, we observe substantial growth in healthcare expenditures. The Capital health expenditure (CHE) has seen a remarkable increase from 856 million US$ in 2000 to 92,430 million US$ in 2020 as shown in Figure 1.

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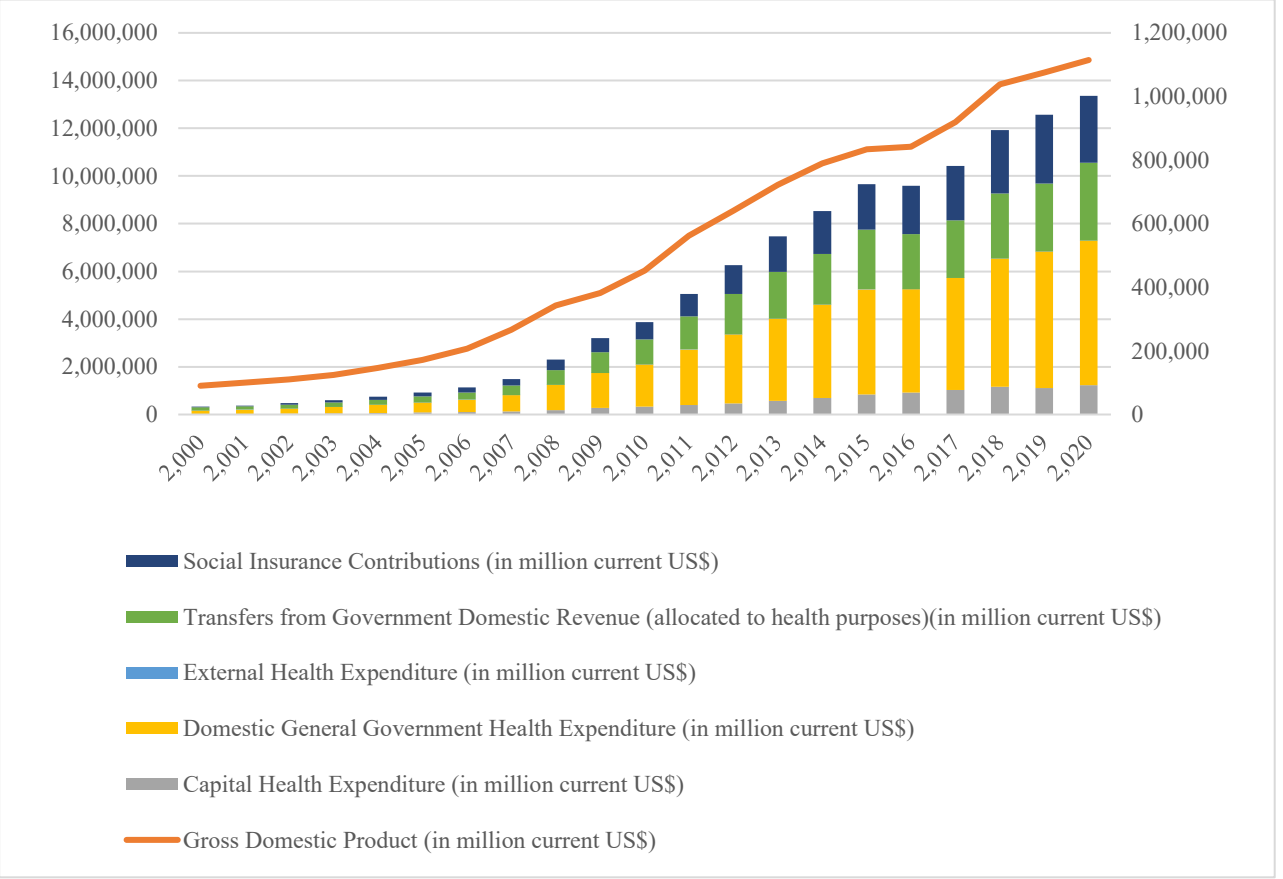

Figure 1: China's economic indicators in the health sector from 2000 to 2020.

Moreover, in Figure 1, Domestic General Government Health Expenditure (GGHE-D) rose from 11,943 million US$ in 2000 to 454,947 million US$ in 2020, while External Health Expenditure (EXT) fluctuated but exhibited an overall upward trend, reaching 310.767 million US$ in 2020.

Before to analyse specific variables, the regression model with an R-squared value of 0.998 indicates that nearly all of the variability in GDP is accounted for by the independent variables. The F-test, with a low p-value, confirms the model's overall statistical significance. The model's Akaike and Bayesian information criteria (AIC and BIC) suggest a good fit, with lower values indicating better model fit.

Referring to Table 3, our regression analysis indicates that two of these healthcare expenditure indicators, GGHE-D and EXT, have a statistically significant impact on China's GDP. GGHE-D exhibits a positive coefficient of 32.02, with a near-zero p-value, indicating a strong positive association between government healthcare expenditure and GDP growth. Similarly, EXT has a substantial coefficient of 4856.463, with a tiny p-value, suggesting that external health expenditure also significantly contributes to GDP growth.

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Table 3: Linear regression for China's economic indicators.

GDP	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
CHE	23.483	15.167	1.55	.141	-8.67	55.635	
GGHE-D	32.02	6.847	4.68	0	17.505	46.535	***
EXT	4856.463	637.395	7.62	0	3505.246	6207.68	***
TransGDR	-9.236	9.533	-0.97	.347	-29.445	10.973	
Constant	637406.31	126482.76	5.04	0	369274.84	905537.77	***

Mean dependent var	6940169.337	SD dependent var	4794642.214
R-squared	0.998	Number of obs	21
F-test	2635.980	Prob > F	0.000
Akaike crit. (AIC)	578.320	Bayesian crit. (BIC)	583.543

*** $p<.01$, ** $p<.05$, * $p<.1$

Moreover, TransGDR allocated to health purposes, experienced a fluctuating pattern over the years, ranging from 10,050 million current US$ in 2000 to a peak of 244,763 million current US$ in 2020 from Figure 1. Despite variations, Table 3 shows it did not exhibit a statistically significant impact on China's GDP in the linear regression analysis.

In summary, based on WHO data and regression analysis, we can conclude that healthcare expenditure, particularly GGHE-D and EXT, has a substantial and statistically significant impact on China's GDP growth. This highlights the relevance of healthcare investments in shaping the economic landscape of China.

3. Description of Brazil

In the case of Brazil, the healthcare landscape witnessed notable trends and transformations during the period under examination. Drawing upon data from the WHO and the linear regression analysis, we can provide insights into the state of healthcare in Brazil. In Figure 2, from the year 2000 to 2020, Brazil's GDP showed fluctuations, starting at 655,449 million current US$ in 2000 and reaching 1,448,566 million current US$ in 2020.

DOI: 10.54254/2754-1169/62/20231344

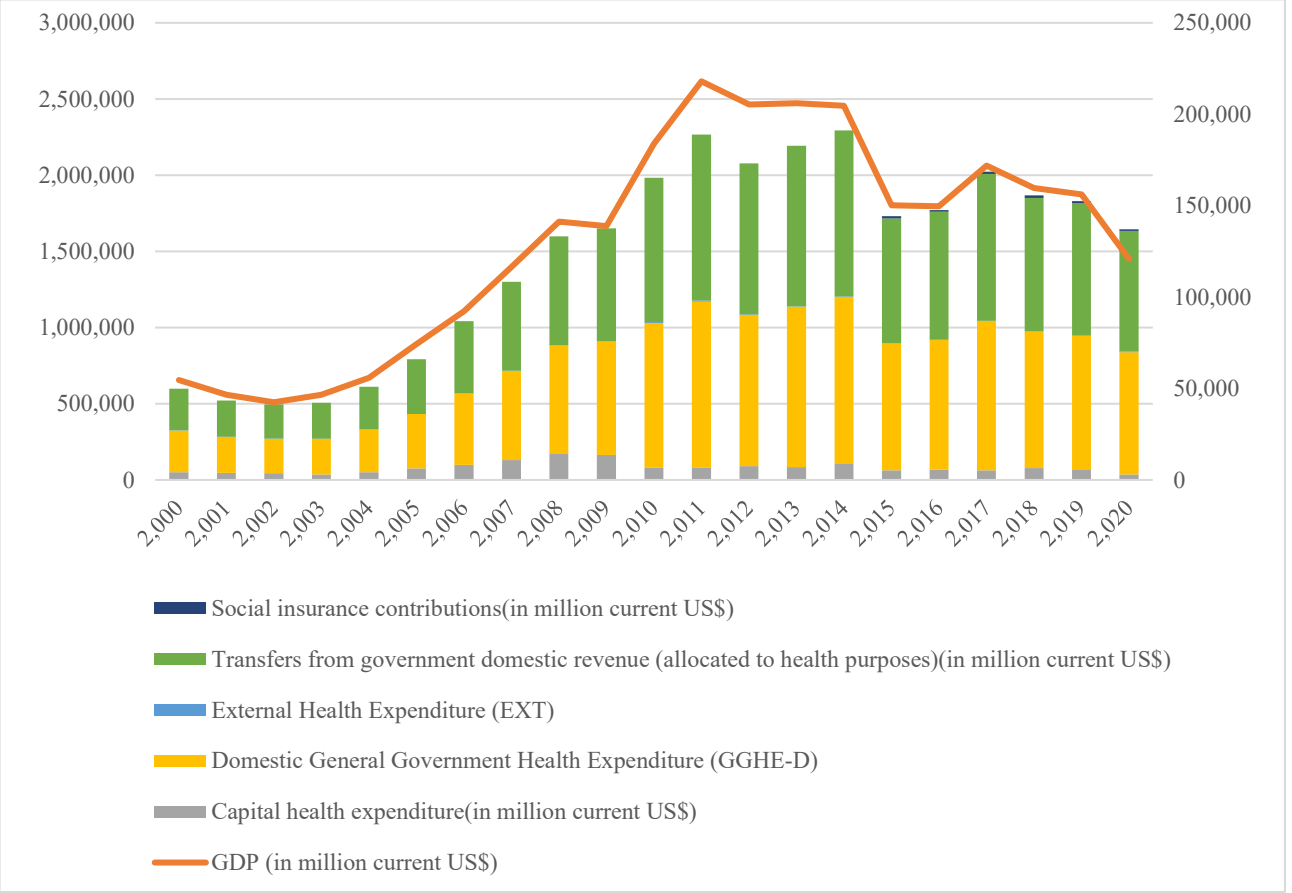

Figure 2: Brazil's economic indicators in the health sector from 2000 to 2020.

When analyzing healthcare indicators, the regression model exhibits robust explanatory power, evident from the R-squared value of 0.986. The F-test, with a near-zero p-value, confirms the model's overall statistical significance. Both the AIC and BIC are relatively low, suggesting a good fit and parsimonious model.

To be specific, Figure 2 shows CHE remained relatively stable, with limited variation, hovering around 4,000-9,000 million current US$. In contrast, GGHE-D exhibited a decline from 22,745 million US$ in 2000 to 66,854 million US$ in 2020. EXT and TransGDR displayed less consistency but did not exhibit strong trends.

In particular, Table 4 shows GGHE-D had a significant negative coefficient of -150.65 in the linear regression analysis, with a p-value of 0.016, indicating that government healthcare expenditure had a statistically significant negative impact on Brazil's GDP during the examined period. This finding raises questions about the efficiency and effectiveness of government healthcare spending in Brazil and its implications for economic growth. Moreover, TransGDR allocated to health purposes in Brazil, exhibited a statistically significant positive impact on GDP in the linear regression analysis. With a substantial coefficient of 178.326 and a low p-value of 0.006, TransGDR contributed significantly to Brazil's economic growth during the studied period, highlighting the importance of these transfers in the healthcare sector's relationship with the economy.

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Table 4: Linear regression for Brazil's economic indicators.

GDP	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
CHE	4.369	8.69	0.50	.622	-14.053	22.792	
GGHE-D	-150.65	56.072	-2.69	.016	-269.517	-31.783	**
EXT	42.046	191.512	0.22	.829	-363.94	448.033	
TransGDR	178.326	56.932	3.13	.006	57.636	299.016	***
Constant	-14100.243	64499.412	-0.22	.83	-150832.89	122632.4	

Mean dependent var	1563393.846	SD dependent var	707932.539
R-squared	0.986	Number of obs	21
F-test	292.104	Prob > F	0.000
Akaike crit. (AIC)	543.922	Bayesian crit. (BIC)	549.145

*** p<.01, ** p<.05, * p<.1

In summary, Brazil's healthcare situation, as reflected in the provided data and analysis, highlights the need for further examination and policy evaluation regarding the impact of government healthcare expenditure on the economic performance. This highlights the necessity of making healthcare policy decisions based on solid evidence to efficiently allocate resources and ensure the well-being of the population.

4. Comparison of China and Brazil

4.1. Empirical analysis

The analysis of economic indicators, particularly GDP, and the comparison of healthcare investment in medical technology between China and Brazil reveal notable differences in economic size, growth trends, and industrial structure.

Firstly, the Figure 3 shows that China's GDP (overall mean: 4,251,782 million current US$) is considerably larger than Brazil's GDP (overall mean: 1,563,393 million current US$) over the studied period. China exhibits higher GDP growth trends and a more diverse industrial structure, as evidenced by its larger standard deviation.

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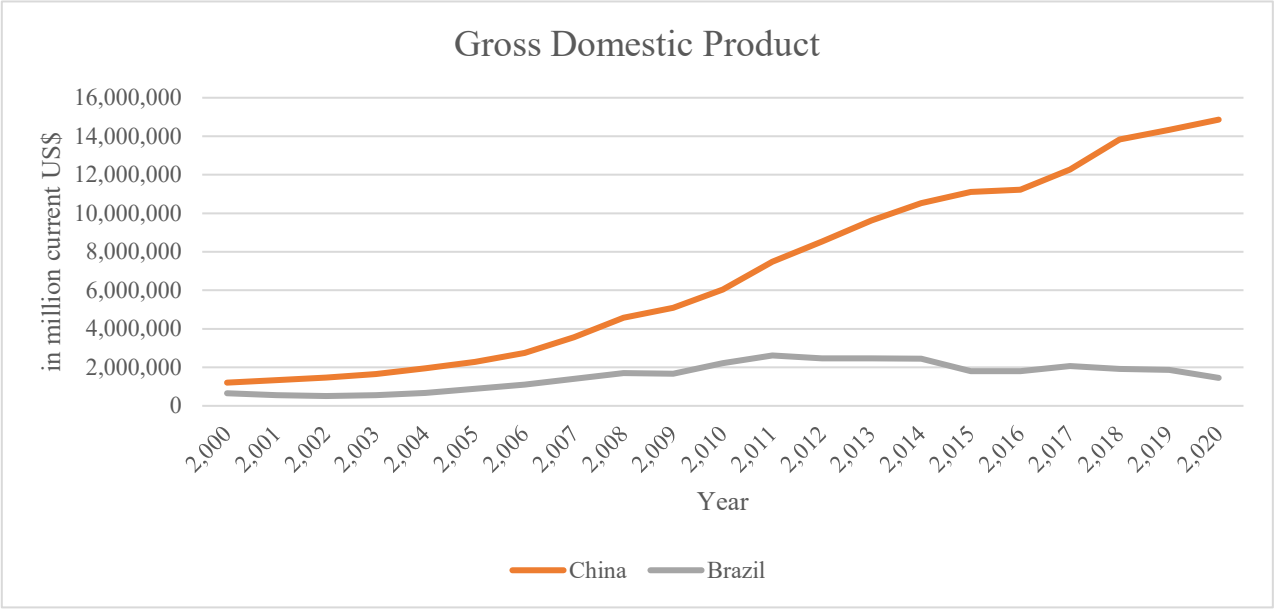

Figure 3: GDP of China and Brazil from 2000 to 2020.

Secondly, the regression analysis in Table 5 indicates that in China, GGHE-D and EXT significantly impact GDP, whereas in Brazil, only GGHE-D and TransGDR exhibit significant impacts. This implies that the composition of healthcare spending and its impact on the economy differ between the two countries.

Table 5: Linear regression for China and Brazil's economic indicators.

GDP	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
CHE	-33.612	23.136	-1.45	.155	-80.49	13.266	
GGHE-D	68.434	8.324	8.22	0	51.568	85.3	***
EXT	2304.637	915.947	2.52	.016	448.751	4160.523	**
TransGDR	-56.203	7.972	-7.05	0	-72.355	-40.051	***
Constant	824979.43	180899.22	4.56	0	458442.79	1191516.1	***

Mean dependent var	4251781.592	SD dependent var	4343055.160
R-squared	0.987	Number of obs	42
F-test	1054.057	Prob > F	0.000
Akaike crit. (AIC)	1228.056	Bayesian crit. (BIC)	1236.745

*** p<.01, ** p<.05, * p<.1

Additionally, avoiding muti-collinearity, we use logarithm to some variables. Table 6 presents the pairwise correlations, indicating a strong positive relationship between GDP and technology indicators (GGHE-D and TransGDR) in both countries. However, in Brazil, EXT exhibits a weak positive correlation with GDP, suggesting a less direct impact on economic growth compared to China.

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Table 6: Pairwise correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) GDP	1.000					
(2) lnc	0.918	1.000				
	(0.000)					
(3) lnd	0.883	0.924	1.000			
	(0.000)	(0.000)				
(4) EXT	-0.291	-0.177	-0.047	1.000		
	(0.062)	(0.261)	(0.769)			
(5) lnt	0.764	0.839	0.968	0.025	1.000	
	(0.000)	(0.000)	(0.000)	(0.877)		
(6) SIC	0.988	0.884	0.824	-0.382	0.701	1.000
	(0.000)	(0.000)	(0.000)	(0.012)	(0.000)	

Finally, by Hausman test, Table 7 presents fixed-effects regression results for both countries. In China, technological factors (GGHE-D and TransGDR) have a significant positive impact on GDP, reflecting the country's focus on technology-driven economic growth. In Brazil, GGHE-D, EXT, and TransGDR significantly affect GDP, reflecting a different economic structure with a stronger healthcare influence.

Table 7: Results from the fixed-effects regression.

GDP	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnc	154309.89	41816.529	3.69	.168	-377019.49	685639.26	
lnd	-1409339.4	228530.21	-6.17	.102	-4313091.1	1494412.2	
EXT	881.844	151.364	5.83	.108	-1041.42	2805.107	
lnt	2481403.5	234285.72	10.59	.06	-495478.83	5458285.7	*
SIC	47.359	.344	137.53	.005	42.983	51.734	***
Constant	-10572581	400559.47	-26.39	.024	-15662172	-5482990.4	**

Mean dependent var	4251781.592	SD dependent var	4343055.160
R-squared	0.998	Number of obs	42
F-test	.	Prob > F	.
Akaike crit. (AIC)	1127.283	Bayesian crit. (BIC)	1129.021

*** p<.01, ** p<.05, * p<.1

To summarize, China and Brazil exhibit differences in economic size, growth trends, and industrial structure, as reflected in their GDP and healthcare expenditure impacts. While China places a significant emphasis on technology-driven growth, Brazil's economy is influenced by a combination of healthcare spending and technology-related factors.

4.2. Considering Other Indicators

In addition to the indicators that can be recorded in the data above, there are many healthcare factors that can also affect economic development. Factors such as the policies of both countries in terms of

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healthcare and investment in medical technology, the social environment, and the healthcare system may also affect the GDP, so we need to consider the relevant elements as well.

Overall, the rapid economic growth witnessed in China over recent decades has created an environment conducive to substantial development and investment in healthcare infrastructure. In contrast, while Brazil stands as an upper-middle-income nation boasting the ninth-largest economy on the global stage, it faces economic challenges and political instability limiting its healthcare budget and overall economic growth [3].

In terms of healthcare policy, both countries have developed policies that are appropriate for their countries. So far China has implemented a number of healthcare reforms. Firstly, China's health insurance coverage reached more than 97 percent in 2015 [4]. Secondly, in 2000, out-of-pocket spending on healthcare was as high as 60 percent, but in 2016, this figure was reduced to less than 30 percent [4]. Because Brazil does not have information on this data, it could not be included in the previous model. Moreover, the Healthy China 2030 plan, announced in 2016, emphasizes technology-driven healthcare solutions and investments in medical technology. This suggests that China's top policymakers have acknowledged the extensive spectrum of health determinants and are poised to transition from disease treatment to a comprehensive healthcare approach [5]. If these measures be efficiently executed, China stands to unparalleled achievement in strengthening its healthcare system and improving the health of its population, which further contributes to GDP growth. In contrast, Brazil has been grappling with healthcare policy challenges, including efforts to reduce healthcare disparities and address funding inefficiencies. For example, in the public healthcare sector of Brazil, an in-depth longitudinal analysis of sanitaristas' programmatic actions demonstrates the critical relevance of these professionals [6]. They contributed to the transformation of social protection and developed the public health system against a backdrop of strong opposition to their intervention.

Although both China and Brazil have a strong focus on policy development, the two countries differ in their emphasis on medical research. In terms of research capacity, China has invested significant resources to the research, development and implementation of medical technologies, which has led to significant progress in research and innovation. In particular, investments and subsidies in digital health, telemedicine, and AI-powered diagnostics have transformed the delivery of healthcare services and led to new trends in many more areas [7]. In addition, China's global health organizations are all at different stages of development, each with their own areas of strength - for example, hemophilia surveillance system for the National Health Commission, malaria and other infectious diseases for the Chinese Center for Disease Control and Prevention, and environmental health for Tsinghua University [8] - compared to Brazil, which has struggled to allocate sufficient funding for medical technology, which has affected the efficiency of its healthcare system. Chinese research institutes and universities are becoming increasingly prominent in global medical research. Nonetheless, health research capacity in Brazil exhibits an uneven distribution and tends to be concentrated in regions with higher economic development [9]. WIPO research has shown that a handful of states, such as São Paulo, have research capacities and institutions comparable to those in North America, but the rest of the country is poor [10]. Not only that, but Brazil does not have an adequate talent pool. Although the overall count of researchers in Northeast Brazil surged by over two-fold between 2006 and 2016, the Brazilian government's drastic reductions in research funding pose a substantial risk to recent progress and are contributing to a significant loss of intellectual talent [11]. According to WHO data from 2017, Brazil has a density of less than 0.05 biomedical engineers per 10,000 population, but China has a density of about five biomedical engineers per 10,000 population [12].

In addition to policy development and medical research capacity, international cooperation in healthcare has had a positive effect on boosting GDP growth. China is actively engaged in international cooperation in medical technology R&D and innovation, exchanging knowledge and

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resources with relevant countries and organizations. For example, the Chinese government declared its collaboration with the U.S. government to offer technical assistance to the African Union in establishing the African Center for Disease Prevention and Control in 2015 [13]. While Brazil is involved in international healthcare initiatives, it faces budgetary constraints that limit its contribution to global medical technology research. It is worth noting that the The Belt and Road Initiative presents new opportunities for China and countries along the route, and Brazil's potential participation in the The Belt and Road Initiative in 2023 will help the country to improve on an otherwise missing strategy, while further boosting the two countries' GDP growth in both countries [14].

5. Conclusion

Through this research, we discerned critical trends and relationships. Specifically, we observed that healthcare expenditures, notably GGHE-D and EXT, exerted a substantial and statistically significant influence on China's GDP growth. In contrast, Brazil exhibited a distinct pattern, with GGHE-D negatively impacting its economic output while TransGDR contributed positively. This divergence underscores the variances in the composition and effects of healthcare spending on the two nations' economies.

In the broader context of economic development and healthcare investment, we noted substantial disparities between China and Brazil. China's formidable economic size, robust growth patterns, and diversified industrial landscape contrast with Brazil's comparatively smaller economy and less consistent growth. These distinctions culminate in differing healthcare expenditure impacts, suggesting unique economic structures in the two countries.

Moreover, the correlation analysis substantiated the positive relationship between GDP and healthcare technology indicators, particularly GGHE-D and TransGDR, in both China and Brazil. However, Brazil's EXT exhibited a weaker correlation with GDP compared to China, indicating a less direct economic influence.

This study advances our comprehension of the intricate interplay between healthcare investments and economic outcomes, underscoring the need for further exploration. Future research should delve into healthcare policy dynamics, evaluating their efficiency and effectiveness in light of economic growth. Additionally, the investigation of social determinants, healthcare system structures, and their interplay with GDP merits extensive inquiry.

Looking ahead, there are compelling prospects for future research. The study highlights the significance of evidence-based healthcare policy decisions to optimize resource allocation and ensure societal well-being. Furthermore, international cooperation in healthcare, exemplified by China's active engagement in global healthcare initiatives, holds the potential to bolster GDP growth and contribute to global healthcare innovation.

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